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A review on the development and commercialization of biomass gasification technologies in China

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Abstract

With the fast economic growth, the energy demand in China has increased two-fold in the past three decades. Various energy resources have been exploited and utilized and biomass is one of the energy resources that is abundant and has been widely used in China for a long time. Biomass gasification is an efficient and advanced technology for extracting the energy from biomass and has received increasing attention in the energy market. In this paper the development of biomass gasification for various energy applications in China is reviewed and their prospects are discussed. Among the different biomass gasification technologies, biomass gasification and power generation is found to be the most promising biomass gasification technology that has great potential to be further developed in China.

Keywords: Biomass gasifier; Boiler heating; Domestic cooking; Power generation; Economic analysis; Policy

Contents

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1. Introduction

As the biggest agricultural country, China has an abundant biomass energy resource. About 0.65 billion tons of agricultural residues are produced per annum, which will be increased to 0.73 billion tons in 2010 [1]. This is equivalent to about 12,000 trillion kJ of energy. The quantity of forest residues in China is also enormous, reaches 37 million m^3 (excluding forest firewood) and contains 580 trillion kJ of energy [2]. Taking a fraction of biomass resource out as feedstuff and some as stocks, the remaining amount of solid biomass suitable for energy gener-

ation can give rise to 8800 trillion kJ of energy. While along with the development of agricultural and forestry industry, especially with the exploitation and popularization of fast-grown firewood forest, the solid biomass resource in China will become more and more, having intense exploitation and utilization potential.

Gasification is a technology commonly used nowadays for extracting energy from biomass. Over the past decade, there has been great progress in the development of gasification technology in China. Many kinds of biomass gasification processes have been developed treating different materials for various purposes. The first generation is the up-draught fixed bed gasifier, with gasification efficiency over 75% and maximum energy output of about 10 million kJ/h. This system normally converts wood residues into gaseous fuel suitable as boiler fuel. The second generation is the down-draft fixed bed gasifier, with gasification efficiency around 75% and maximum energy output of 4 million kJ/h. This system is mainly used for treating crop straw and wood wastes for supplying domestic cooking gas, and for wood drying process in factories. The most recent one is the circulating fluidized bed (CFB) gasifier, with efficiency maintains at about 75% but the maximum energy output can be increased to 40 million kJ/h. This system has been operated successfully for treating wood and crop wastes to fuel boiler or to generate electricity.

2. An overview of the development of biomass gasification technologies in China

2.1. Technology development

In recent years, there is a great achievement in the research and development of biomass gasification technology in China. Different technologies have been developed to suit different market demands. Obvious progress has been made in the following two aspects:

2.1.1. Biomass gasifier designs

Based on different biomass characteristics, the performance of various gasifiers has been enhanced. A remarkable progress is the economic production of CFB gasifier and down draft gasifier for corn straw. Simple pre-treatment for different kinds of biomass residues is employed. Table 1 shows the major types of gasifier

Table 1
Major types of biomass gasifier in China [3]

Gasifier type	Up-draft	Open core	Down-draft	CFB
Fuel types	Tree barks, timber block	Husk	Straw	Straw, husk, sawdust
Output	2–30 kWe	60–200 kWe	60–200 kWe	400–2000 kWe
LHV of gas	4100–5300 kJ/m^3	3800–4600 kJ/m^3	3800–4600 kJ/m^3	4600–6300 kJ/m^3
Temperature	~1100 °C	700–800 °C	~1000 °C	650–850 °C
Efficiency (η)	70–75%	50%	75%	65–75%
Application field	Boiler fuel	Electricity generation	Domestic cooking	Boiler fuel, electricity generation

applied in China. As can be seen, different types of biomass residues have been adopted and applied in different fields.

2.1.2. Fuel gas utilization processes

According to available biomass resources and energy demands in China, biomass gasification technology has been mainly applied in three areas. The first is biomass wastes gasification combined with heating equipment (such as drying equipment and boilers) directly. In this case, coal or oil can be substituted by the gas produced and thus benefited from conserving energy. The second is straw gasification for domestic cooking application. Such systems can make use of most of the agricultural waste, converting it to domestic cooking gas, and supplying rural areas by setting up small gas stations with pipe network. This technology takes an important role in upgrading the living conditions of rural areas in developing countries. The third is biomass gasification and power generation system (BGPG). Such systems can provide power and electricity by making use of different kinds of biomass in any desired scale. It is suitable for domestic and small industrial applications particularly in rural area, such as rice mill, timber mill and food processing. BGPG is the most promising biomass technology that will be widely applied in developing country because of its flexibility and economy.

Table 2 provides further information of the above-mentioned biomass gasification systems that have been adopted in China for drying and heating, domestic cooking, and power generation areas. These are the necessary data for determining the economic indices of different kinds of technology.

2.2. Technology features

Biomass gasification is a technology for generating clean renewable energy. It can convert dispersed biomass waste to good quality fuels and electricity suitable for different applications and transportations. Thus, it accords with the trend of developing separated energy system, and improves biomass applicability effectively. It is of great importance to those rural areas and developing countries faced with shortage of electricity.

2.2.1. Application advantages

2.2.1.1 Extensive applicability. Through pre-treatment technology, all kinds of biomass residues, including wood waste, straw, rice husk and bagasse, can be

Table 2
Major applications of biomass gasification system

Application	Drying and heating	Domestic cooking	Power generation
Gasifier type	Down-draft	Down-draft	CFB
Gas cleaner	No	Water scrubber, filter	Dust separator, water scrubber
Pre-treatment	Cutting	Cutting	Crushing
System efficiency (%)	70–80	75	16–18
Operation time (h/year)	6000	2000	5000
Lifetime (years)	10	20	15

converted to combustible gases. Thus, biomass gasification is applicable to deal with all kinds of biomass residues produced in the food processing industry, agriculture, forest industry, etc. The gases can be burned in boilers or used for drying kilns directly. After tar removing and cleaning, these combustible gases can also be transported and used for domestic cooking and internal-combustion engines. Therefore, biomass gasification can be employed to meet different market needs.

2.2.1.2 Scale flexibility. With various gasifier types and processes, biomass gasification system can be designed in appropriate scale according to user demands. The system can be operated stably and kept with reasonable technical indices in any scale. However, too small a scale decreases the economic indices, and too large a scale creates problems in providing feedstock. Therefore, appropriate scale must be decided by local conditions, such as the amount of biomass wastes, demands of energy (kinds and output), etc.

2.2.1.3 Economic feasibility. Because of the dispersed distribution and massive volume, biomass residues are difficult to utilize and have therefore been usually treated as waste. Small- and medium-scale biomass gasification systems can fully utilize these biomass residues in a small district, avoiding collection and long distance transportation problems. This enhances the competitiveness of biomass gasification with other energy technologies in the market. From the economic point of view, the keys to make biomass gasification economically feasible are to cut down the investment cost and to extend its application areas. In China, most of the biomass gasification systems are economically feasible if the fuel gas produced is used to generate electricity or to replace fuel oil, and if the system is of an appropriate scale.

2.2.2. Application obstacles

The following are some disadvantages of small- and medium-scale biomass gasification applications:

1. Limited by the capital cost, the system needs to be as simple as possible. Therefore, some important processes, such as tar removal and gas cleaning, cannot be perfectly designed, leaving some operation difficulties and environmental problems [4].
2. In recent years, there is a high demand for environmental protection, as well as energy saving all over the world. However, not all biomass gasification technologies can meet this demand. For example, gasification of straw for domestic cooking system can achieve obvious social benefit, but due to the high cost for antipollution measures it is impossible to make profit from its use.

Therefore, unless municipal government offers assistance for development, it will take a long period of industrialization process to reflect the importance of biomass gasification in energy and environmental protection field.

2.3. Demonstration projects

In the previous three China's national plans, (7th to 9th Five-year Plan covering the period 1986–2000), biomass gasification had played an important role in the energy developments. In order to promote its application and industrialization, some excellent demonstration projects have been built and operated successfully in this country. Table 3 lists some of the earliest demonstration projects that have been successfully operating in China.

Biomass gasification for heating mainly includes wood drying and boiler heating, and all these projects are sponsored by private enterprises without any assistance from the government. For power generation projects, some local governments have provided some financial supports at the beginning of its development, but now almost all projects are economically independent. Nevertheless, most of the domestic cooking fuel projects have needed government financial support till now.

2.4. Technology developers and providers

Under the government's strong support, many companies and factories specialized in biomass gasification have been set up in recent years. It is estimated that there are more than 40 factories and enterprises that provide biomass gasification equipment and facilities in China.

3. Economic analysis

3.1. Investment and capital cost

The capital cost of biomass gasification system mainly comes from: (1) gasifier and gas cleaning system; (2) fuel gas utilization equipment; and (3) fittings and sys-

Table 3
Typical biomass gasification demonstration projects in China

Project	Material	Purpose	Capacity	Gasifier	Location
(a) Gasification for heating					
Huairou Wood Equipment	Sawdust	Drying	200 kWt	Down draft	Beijing
Zhanjiang Timber Mill	Wood powder	Boiler	1000 kWt	CFB	Guangdong
Lushuihe Timber Mill	Wood powder	Boiler	7000 kWt	CFB	Jilin
(b) Gasification for cooking					
Huantai Integrate Gas-supply System	Crop residues	Cooking	300 kWt	Down draft	Shangdong
Dalian Biomass Pyrolysis and Gas System	Wood residues	Cooking	700 kWt	Fixed bed	Liaoning
Dalian Integrate Gas-supply System	Crop residues	Cooking	300 kWt	Down draft	Hunan
(c) Gasification for Power Generation					
PutianHuagang Rice Mill	Rice husk	Electricity	1000 kWe	CFB	Fujian
Sanya Timber Mill	Wood powder	Electricity	1000 kWe	CFB	Hainan
Handan Steel Works	Corn straw	Electricity	600 kWe	CFB	Hebei

tem construction. The economic data of different biomass gasification systems are shown in Tables 4–6.

Table 4
Economic data of biomass gasification and heating system (based on 10 years lifetime and 6000 h operation time per year)

Capacity	200 kW_t	1000 kW_t	3000 kW_t	7000 kW_t	10,000 kW_t
Purpose	Dying	Boiler	Boiler	Boiler	Boiler
Capital cost (10^3 US$)					
Gasifier and fittings	6.2	24.6	36.9	55.3	73.8
Control unit	0.6	1.3	1.3	1.3	1.3
Base and buildings	0.6	1.3	1.3	1.8	2.5
Installation	0.6	2.5	3.7	4.9	6.2
Design and regulation	1.3	2.5	2.5	2.5	2.5
Total capital cost	9.3	32.2	45.7	65.8	86.3
Capital cost US$/$kW_t$	46.5	32.2	15.2	9.4	8.6
Operation cost (10^3 US$)					
Power consumption	1.0	1.8	3.7	5.5	6.8
Maintenance	0.6	1.3	1.8	2.5	3.7
Labour cost	2.4	5.4	5.5	5.5	5.5
Total operation cost	4.0	8.5	11.0	13.5	16.0
Operation cost 10^{-8} US$/kJ	9.3	3.9	1.7	0.9	0.7

Table 5
Economic data of typical biomass gasification and gas-supply system (based on 20 years lifetime and 2000 h operation time per year) [5,6]

Capacity		180 kW_t (100 families)	500 kW_t (300 families)	800 kW_t (500 families)
Capital cost (10^3 US$)				
Gasification system	Gasifier and gas cleaner	12.3	14.7	18.4
	Fittings	2.5	2.5	2.5
	Installation	1.8	1.8	2.5
Gas supply system	Gas tank	14.7	22.1	36.9
	Gas tubes	4.9	14.7	24.6
	Fittings	6.0	18.1	30.1
	Installation	5.5	11.1	16.6
Others	Base and buildings	6.2	9.8	12.3
	Design and regulation	1.8	3.1	4.3
Total capital cost		55.7	97.9	148.2
Capital cost US$/$kW_t$		310	196	185
Operation cost (10^3 US$)				
Power consumption		0.6	1.3	2.6
Maintenance		1.0	1.5	2.7
Labour cost		2.4	3.2	3.7
Total operation cost		4.0	6.0	9.0
Operation cost 10^{-8} US$/kJ		15.4	8.3	7.8

Table 6
Capital and operation cost of biomass gasification and power generation system (based on 15 years lifetime and 5000 h operation time per year) [7,8]

System capacity	200 kW	600 kW	1000 kW	1500 kW	2000 kW
Capital cost (10^3 US$)					
Gasifier and gas cleaner	19.7	43.0	61.5	73.8	86.1
Gas engine system	43.0	129.1	215.2	295.2	393.6
Fittings	6.2	12.3	18.4	24.6	36.9
Base and buildings	6.2	24.6	36.9	49.2	61.5
Installation	6.2	18.4	24.6	36.9	49.2
Design and regulation	4.9	12.3	12.3	12.3	12.3
Total capital cost	86.2	239.7	368.9	492.0	639.6
Capital cost US$ / kW	431	400	369	328	320
Operation cost (10^3 US$)					
Material consumption	5.5	16.6	27.7	38.6	51.6
Maintenance	1.8	4.9	7.4	9.9	12.3
Labour cost	12.2	24.5	36.9	43.0	49.1
Total operation cost	19.5	46.0	72.0	91.5	113.0
Operation cost 10^{-8} US$/kJ	36.1	28.4	26.7	22.6	20.9

As can be seen from the tables, the unit capital cost of all the biomass gasification and heating systems quoted here are less than 50 US$/kW. This low cost is due to the fact that special collection, transportation and storage equipment are not needed for such systems. This is much lower than that of a typical domestic cooking system and a power generation system. Of course, for economic reason such systems would only be constructed in locations where drying kilns or boilers exist. Compared with traditional energy technology, the investment on a gasification system for cooking is much higher than that of LPG cooking equipment or other types of stoves. In contrast, the investment on a biomass gasification and power generation system will be less than that of a coal fired power station but higher than that of a diesel engine power station. Similar to other technologies, the unit investment will be decreased when system capacity increases. It can be found that any kind of gasification systems should has a lower scale limitation because of the high capital cost in small scale.

3.2. Operation cost

The operation cost of a typical biomass gasification system consists of power consumption cost, cost for equipment maintenance, equipment depreciation and labour cost. For biomass gasification and power generation systems, and domestic gas supply systems, their system operation cost lies between 2.1×10^{-7} to 3.6×10^{-7} US$/kJ and 0.8×10^{-7} to 1.5×10^{-7} US$/kJ, respectively, excluding biomass cost and equipment depreciation (Tables 5 and 6). This means that biomass wastes will cost much more when they are used in the same way as fuel gas. Equipment depreciation is determined by capital cost and equipment lifetime and the capital cost is notably affected by the total operation time. Based on the test results of the

demonstration projects, it can be estimated that biomass gasification system for heating or for generation would operate more than 20 h per day and the gasification and domestic cooking system only work for about 6 h per day.

Taking into account all of the above factors and biomass cost, the overall cost of the energy generated from biomass gasification system can be estimated. For example, if equipment depreciation is excluded, the electricity cost of biomass gasification and generation is about 0.03–0.04 US$/kWh. It has been found that the cost of electricity generation from biomass gasification is close to that of small-scale coal fired power plants, but much lower than that of diesel engine power plants when the biomass price is less than 1.2×10^{-6} US$/kJ. However, for small-scale plants, the proportion of labour cost and maintenance charge will be increased sharply. Accordingly, the power generation cost will rise higher as the power capacity changes less. When the power is less than 200 kW, the power generation cost will be close to large-scale diesel engine power generation level, losing competition advantage. From the cost sensitivity analysis, it can be found that the most important factors that affect overall operation cost are: system capacity, biomass cost and operation time.

3.3. Economic analysis

From an economic point of view, profit can only be obtained by biomass gasification when it is much cheaper than other kinds of energy. A simple way has been adopted to decide whether or not a biomass gasification project is cost effective. A project is profitable (i.e. $P_r > 0$) means that all the investment can be reclaimed within the equipment lifetime. Otherwise, the project will become deficit and need some financial assistance to sustain. The ability of a project to have a positive gain can be analysed as follows:

$$P_r = (P_1 - P_2/\eta) - (C_1 + C_2)$$

where P_r is the profit of biomass energy, US$/kJ; P_1, the price of energy produced from biomass gasification system, US$/kJ; P_2, the price of biomass, US$/kJ; η, system efficiency, %; C_1, capital cost of biomass gasification system, US$/kJ; C_2, operation cost of biomass gasification system, US$/kJ. Additionally, investment project should be targeted to pay back all its investment as soon as possible and obtain profits comparable to other investment of traditional energy projects. For example, the investments of most of the biomass gasification projects in China have a pay back period of less than 5 years. The acceptable economic feasibility can thus be shown as follows:

$$R_e = I_n/(P_r \times T \times 3600) \leq 5$$

where R_e is the payback period (ratio of total investment to annual profit), year; I_n, investment of biomass gasification project, US$/kW; T, operation time, h/year.

The energy price of different energy resources in southern China is shown in Table 7. Based on this information, the economic indices of some existing typical biomass gasification projects are calculated and shown in Table 8. Through pen-

Table 7
Price of different energy types in southern China (including transportation cost)

Energy type	Electricity	Diesel/oil/LPG	High quality coal	Low quality coal	Straw	Rice husk	Sawdust
Price (10^{-6} US$/kJ)	17.0	5.5	1.7	1.2	0.8	0.7	0.7

etrating analysis into the factors related to the economic feasibility, it has been found that many factors, particularly energy price, investment and operation time will affect the payback period (R_e) drastically. It can be concluded that boiler heating and power generation projects have higher possibility of getting economic advantage, with low pay back period ($R_e \leq 5$) and high internal rate of return. On the other hand, it is very difficult for biomass gasification domestic cooking projects meeting the economic situation in China.

Despite the above cost factors, investigation indicated that many clients that employ biomass gasification technology can be benefited not only by saving energy, but also by handling biomass waste, and settling the problems of waste stockpiling and pollution generated from, for example, rice mills, timber mills and farms. This is the main reason why many biomass gasification projects are still pursued even if the payback period is greater than 5 years.

4. Market analysis of biomass gasification in China

4.1. Application situation

As shown in Table 9, some biomass gasification technologies have been developed in recent years and put into application in a small scale. For example,

Table 8
Economic indices of some typical biomass gasification projects

Purpose	Coal substitution				Family Cooking			Power generation			
Capacity (kW)	1000	3000	7000	10000	200	500	800	200	1000	1500	2000
η (%)	95.0	95.0	95.0	95.0	75.0	75.0	75.0	0.17	0.17	0.17	0.17
T (h/year)	6000	6000	6000	6000	2000	2000	2000	5000	5000	5000	5000
I_n (US$/kW)	32.2	15.2	9.4	8.6	310.0	196.0	185.0	431.0	369.0	328.0	320.0
C_1 (10^{-7} US$/kJ)	2.2	1.1	0.7	0.6	21.5	13.6	12.8	29.9	25.6	22.8	22.2
C_2 (10^{-7} US$/kJ)	4.0	1.7	0.9	0.7	30.9	16.7	15.6	54.1	40.0	33.9	31.4
P_1 (10^{-6} US$/kJ)	1.7	1.7	1.7	1.7	5.5	5.5	5.5	17.0	17.0	17.0	17.0
P_2 (10^{-6} US$/kJ)	0.7	0.7	0.7	0.7	0.4	0.4	0.4	0.7	0.7	0.7	0.7
P_r (10^{-7} US$/kJ)	10.8	14.3	15.5	15.7	2.6	24.7	26.6	85.6	104.0	112.9	116.0
R_e (years)	1.4	0.5	0.3	0.3	167.4	11.0	9.7	2.8	2.0	1.6	1.5
IRR1 (%)	9.0	55.0	72.0	78.5	<0	0.0	0.05	8.5	16.0	20.0	21.0
IRR2 (%)	15.0	64.6	80.0	85.0	<0	3.5	3.5	15.0	23.0	28.0	29.0

R_e, pay-back time without any tax; IRR1, internal rate of return after income-tax; IRR2, internal rate of return without income-tax.

Table 9
Application of biomass gasification technologies in China [9]

Application	Capacity	No. of application	Volumetric/energy of gas produced
Domestic cooking	100–1000 kWt	164 sets	45.7 million m^3
Wood drying	100–500 kWt	370 sets	560×10^9 kJ
Boiler heating	1000–10,000 kWt	15 sets	15×10^6 kW.h
Electricity generation	200–1500 kWe	150 sets	15×10^6 kW.h
Total			~9×10^{11} kJ (per year)

about 160 sets of gasification system have been operated for domestic cooking by independent users or through centralized gas supply networks, 370 sets for wood drying processes and about 150 sets for electricity generations. The total biomass energy converted into fuel gas by gasification rose up to 0.9 trillion kJ. The energy output distribution of different kinds of application system is illustrated in Fig. 1. It shows that most of the energy derived for biomass gasification is used for wood drying industry followed by domestic cooking.

4.2. Market potential

China is the biggest agricultural country in the world producing huge quantities of biomass residues. According to current biomass resources, if only 1% of straw stalk and 10% of rice husks are used for gasification and power generation, the total installed capacity would be greater than 2 million kW. If the residues of forestry and other industries are also taken into account, the market potential will even be stronger.

The primary advantages of biomass gasification technology are environmental protection and energy saving. This mainly aims at clients in rural areas, village/town enterprises, and industrial enterprises that need to process biomass wastes. In recent years, there are a number of timber mills and farms that show interest in

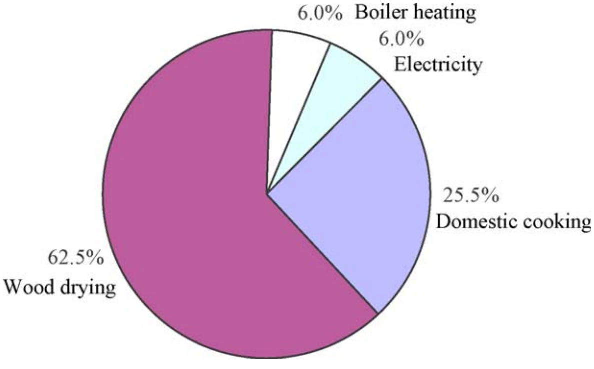

Fig. 1. Distribution of energy output from biomass gasification technology.

processing waste sawdust and agriculture straw stalks respectively. Nevertheless, the technology has not been fully developed to meet all client' demands.

Along with the comprehensive development of rural area economics, and the improvement in society's environmental protection consciousness, it can be foreseeable that the demand for biomass gasification will be increased apparently, as reflected in the following aspects:

1. With the improvement of rural area living standard and the speeding of industrialization step, the demand for combustible gases and electricity will be sharply increased in rural areas. Biomass gasification can meet the demands of separated and independent clients in remote local areas where biomass feedstock is steady and convenient. Therefore, there is an increasing demand for biomass gasification in rural and mountain areas.
2. With the fast growing of industries, the residues produced from wood and food processing industries increase tremendously in recent decades. For example, the scales of rice and oil mills grow larger and larger, and the possibility of processing their residues and providing energy for these plants is highly increased. So the market penetration of biomass gasification will be increased. Biomass gasification unit will become one of the suited equipment in these enterprises.
3. Enhancement of environmental protection awareness in society also provides the development space for biomass gasification and power generation technology. The processing of large quantities of agriculture straw stalks has received much attention in society. Through biomass gasification and power generation, large quantities of agriculture straw stalks can be processed and converted to electricity for internal use or for transmitting to local electric network. This can radically settle the environmental protection issue caused by agriculture straw stalks and reduce energy wasting. Assuming agriculture straw stalks density being 350 t/km^3, the collection radius of 2000 kW gasification and power generation station will not extend beyond 10 km, therefore it is completely possible to popularise straw stalk gasification power stations in agricultural areas.

4.3. *Obstacles to commercialization*

4.3.1. *Technical barriers*

There are three main technical barriers to the commercialization of biomass gasification: secondary pollution, equipment reliability and client orientated product development. These issues are caused by the immature technology that makes it difficult to open market and commercialize. Among these issues, wastewater processing is a first order technical barrier that needs to be solved. Techniques in handling wastewater and other environmental issues will be discussed in Section 5.1.1.

4.3.2. *Economic barriers*

There are three aspects that affect the economy of biomass gasification: investment channel, collection and transportation cost, and electricity price purchased by power grid operators. Electricity incorporated into the power grid is a precondition

that assures a steady profit of biomass gasification power stations. There is no regulation in China regarding the incorporation of electricity derived from biomass into existing grid network. For the sake of local benefit, most of the electric companies/departments do not want to provide reasonable subsidy to biomass energy, even not allowing these scattered power generation equipment to be incorporated into their networks. This badly affects the economy of biomass gasification and power generation technology, thus affecting investment enthusiasm, and impeding the commercialisation of this technology.

4.3.3. External factors

Since the economy of biomass gasification relies mainly on the source of biomass residue and the way of energy utilization, the successful application of this technology depends more on the policy of local municipal government than on the technology side, as China has already developed relevant technology with sufficient experiences. On the other hand, international pressure in reducing greenhouse gas emissions may induce some momentum in promoting the use of renewable energy and hence the biomass gasification technologies.

5. Keys to promote commercialization of biomass gasification technologies in China

5.1. Technical improvement

5.1.1. Solving secondary pollution problems

The primary purpose of biomass gasification and power generation is to process wastes. Currently, because of better external conditions gasification and power generation has received much greater economic advantage, but the pollution issue has not yet been fully resolved and becomes the main barrier of popularizing of this technology. Ash and wastewater management is the key focus during the development of biomass gasification and power generation technology. From the technological point of view, the handling of ash is simpler, raising gasification efficiency and calcining the ash can meet the requirement. The handling of wastewater is more complicated. The fundamental method is to reduce tar output, such as the use of catalytic cracking method, which can be applicable only when the scale of equipment reaches a certain size. As to small-scale equipment, simple physico-chemical processing of wastewater is a practicable method commonly used.

5.1.2. Improving conversion efficiency

From the economic analysis of biomass gasification and power generation it is known that the most important factor that affects the economy of the system is the scale of power generation, while the most principal expenditure among the different operation costs is the fuel charge. Because the labor cost and capital investment dominate, the cost of power generated from a small-scale gasification and power generation system is even higher than that generated by diesel fuel. Therefore, the cost can be reduced significantly only when the scale of the system is big enough.

When the scale reaches a specified size, fuel charge becomes the main cost. At this time power generation cost can be reduced by reducing fuel charge, which can be done effectively by improving total power generation efficiency. Therefore, the most usual ways of decreasing power generation cost are to enlarge power generation scale and to improve power generation efficiency. The latter way is the main emphasis of most current research, whereas in areas where fuel is cheaper, proper power generation scale is more important.

5.1.3. Development of gasification systems

Most food processing factories in China are small- to medium-scale enterprises, but the quantity of food processing is large. The rice processing capacity varies from 50 to 300 tons/day. Rice mills with capacity greater than 300 tons/day are rare. The power consumption of these processing factories ranges from 160 to 2000 kW. Under this scope of work and power requirement the best technology scheme is to employ gasification and power generation using the waste biomass generated from the process. However, the specifications and models of current gasification and power generation units are far from meeting the demands of different clients, so it is necessary to develop a series of gasifiers with different capacities ranging from 200 to 2000 kW. On the other hand, considering that in most other processing factories the electricity consumption is not big, so the excess electricity produced by its own gasification and power generation system should be incorporated into existing electricity network. Under the current sate electricity regulations of China, the scale of unit incorporated into electricity network cannot be less than 500 kW; therefore it becomes necessary to develop power generation units with single unit power 500 kW or larger. Market demand indicated that the main target of current research is on high-power gasification and power generation system.

5.2. Policy support

5.2.1. Increasing support funds, and enhancing investment system innovation

The main task of policy support is to increase funds devotion, make corresponding measures, and resolve the source of start-up funds to form smooth investment channels. All these should be aimed at the current status of biomass gasification and power generation technology and the investment problem met in the market. The following works should be carried out by the government to support the development:

1. Setting up of special project assessment institute, providing references or sponsorship for financial institutes and promoting investment institutes participating in biomass energy trade.
2. Setting up special funds for carrying out pilot development with an aim to drive society investment, and cultivate mature market.
3. Strengthening the collaboration between technological companies and investors for funds raising.

5.2.2. Guarantee purchasing of electricity

Since the single unit capacity of current gas engine in China is comparatively small (~200 kW), which cannot fulfil related state requirements for incorporating into electricity network. Yet as a kind of renewable energy, biomass has important significance in reducing pollution and protecting our environment, therefore the state should implement encouraging and protection policy in this aspect. Besides, small-scale unit (i.e. <100 kW) should be permitted to be incorporated into existing electricity grid, and the lowest purchase price should be specified to ensure the purchase of biomass electricity. Although efficient measures have not been employed in the past to stimulate the activity of electric departments and fulfil the price subsidy channel, some relevant state departments have started to make policy in this direction. The state government should set up forceful renewable energy quota system to ensure local electric company/department to develop or purchase a minimum amount of electricity obtained from renewable energy, and to impose corresponding electricity environmental charge. This charge should be utilized to subsidize electricity generated from clean energy. Many developed countries have had mature policy in this aspect with plenty of successful experiences.

5.2.3. Tax relaxation

As indicated in Section 3.3, some of the biomass gasification projects, such as domestic cooking projects, are difficult to meet the economic situation in China but yet they have their own merits and contribution in reducing pollution. In order to make these projects sustainable, the municipal government should implement relevant policies such as to reduce the profit tax and to reduce interest rate to the loan related to the investment. These incentives can increase the profit capability and attract more investments.

5.3. Technology demonstration

Biomass gasification and power generation has much better market environment in developing countries as compared to developed countries. However, from cost analysis, even the secondary pollution issue can be settled, biomass collection and transportation on large-scale remains a problem that would increase power generation cost, hence reduce its competitiveness. Therefore, under the current condition of having no special protection policy, the main users of biomass gasification and power generation are likely those enterprises/areas where large quantities of biomass residues exist without any collection and transportation issues. In order to fully reveal the advantages of BGPG technology both economically and technically, it is necessary for these enterprises to demonstrate commercialization, so as to allow BGPG to be accepted gradually. Based on this, the technology performance of BGPG should be improved, and a special oriented policy of support should be put into practice to enhance the possibility of applying BGPG with reasonable scale for processing biomass residues such as agriculture straw stalks or forest wastes.

6. Conclusions

The development of biomass gasification technologies in China is discussed. There are three main kinds of biomass gasification systems used, respectively, for drying and heating, domestic cooking, and power generation. Among the different gasification technologies, the biomass gasification and power generation system is the most promising biomass technology that has great potential to be further developed. Though there is a great achievement in the research and development of this technology, several developmental constraints exist including pollution issues, competitiveness with electricity generated by conventional fuel, and the problem of transmitting the electricity into the local electric grid. The system scale also affects the economic feasibility of the technology. At present, only the boiler heating and power generation projects with appropriate scale are economically viable but environmental protection and energy conservation may be a driving force of further development of the biomass gasification technologies in China.

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